

Three Equations Method for Normal Concrete Mix Design

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Abstract

Considerable study, particularly in the last decades has led to a much better understanding of the structure and behavior of concrete, which has been accompanied by an improved and more sophisticated technology and the product current made, in its variety of forms, is much more capable of satisfying the increasingly stringent demands required. Because the behavior of both fresh and hardened concrete is significantly related to their composition, it should be possible, at least in principle, to choose the latter to provide satisfaction in the former. This is mix design; the choosing of the ingredients to provide, economically, concrete possessing desired properties. It implies the deliberate proportioning of cement, fine and coarse aggregates and water, taking into account not only the specified concrete properties but also the characteristics of the specific materials used. The standard methods of designing concrete mixes depend on experience of how concrete mixes behave when made with certain familiar representative materials. This experience is collected in charts or tables which are used as a starting point in choosing mix proportions for laboratory trial mixes. Tests on these trial mixes then indicate what adjustments need to be made. Currently, there are many international methods locally approved for mix designs. The ACI and BS methods are the most commonly used. Along with the aforementioned methods, there are many other methods used for concrete mix design, such as "The Three Equations Method (Bolomeya Method)", which will be illustrated in this paper, in addition to the assessment of the laboratory results of concrete mixes produced by this method.

Keywords

Bolomeya Method; Mix Design; Concrete; Three Equation Method

Introduction

The behavior of concrete, whether fresh or hardened, depends basically on the behavior of its components and the relationship between them, therefore, obtaining a concrete with certain properties depends fundamentally on the concrete mix design. Concrete mix design generally includes two main steps: 1- Selection of the main components suitable for the

concrete (cement, aggregate, water, and additives); 2- Determination of more economical mix ratios to fulfill the workability, strength and efficiency requirements. Currently, there are many international methods locally approved for mix designs, all of which are related to each other, giving relatively the same quantities of the mix components and capable of providing a good concrete mix. It is important to consider that these methods give approximate quantities which should be checked by experimental mixes in order to obtain results suitable for the requirements of the local environment and local materials. The ACI and BS methods are the most commonly used. These methods depend on graphs and standard tables derived from previous research experience and actual concrete production as well as studies of the properties of the materials used. Along with the aforementioned methods, there are many other methods used for concrete mix design, such as "The Three Equations Method (Bolomeya Method)", which will be illustrated in detail in this paper, in addition to the assessment of the results of concrete mixes produced by this method.

Concrete Mix Design Procedure

The procedure of using this method for concrete mix design is as follows:

1. Determination of the compressive strength of the concrete mix to be designed (field strength) [f_c' (req.)];
2. Calculation of the concrete compressive strength in the laboratory, [f_c' (lab.)]. as shown in Eq.(1).

$$[f_c' \text{ (lab.)}] = 1.3 * [f_c' \text{ (req.)}] \text{ (MPa)} \quad (1)$$

The ratio between the field strength and the laboratory strength depends on many factors, such as accuracy of the equipment, experience, size of the samples, etc.

3. Testing the degree of workability. This factor is determined in the field or in the laboratory using methods such as Slump Cone. The workability

depends on many factors such as density of reinforcement, maximum size of coarse aggregate, casting and method of compaction, etc;

4. Determination of cement-water ratio (C/W) using the first equation of design [Eq.(2-a) and (2-b)], both equations are also known as the First Bolomeya Equation.

$$\frac{C}{W} = \left[\frac{f_c'}{A_1} + 0.5 \right] \quad \text{if} \quad (C/W) < 2.5 \quad (2-a)$$

$$\frac{C}{W} = \left[\frac{f_c'}{A_2} - 0.5 \right] \quad \text{if} \quad (C/W) \geq 2.5 \quad (2-b)$$

Where: C/W is the cement-water ratio, f_c' is the laboratory compressive strength of concrete, A_1 and A_2 are variables depending on size and shape of coarse aggregate used and the compressive strength of cement. The values of A_1 and A_2 are determined using tables as a function of size, shape of aggregate and the compressive strength of cement used in the concrete mix, as shown in Table 1. The value of A_1 is substituted in equation (2-a); if the result is less than 2.5 then the value is obtained; otherwise, the W/C ratio is calculated by using equation (2-b).

5. The required amount of water for the concrete mix (W_{Total}) is calculated using the Second Equation of Design (Eq.3), as follows:

$$W_{Total} = C*(W_c) + A*(W_A) \quad (L) \quad (3)$$

Where: W_{Total} : quantity of water required for the concrete mix (lit./m³), A: weight of fine and coarse aggregate required for the concrete mix (kg/m³), C: weight of cement required for the concrete mix (kg/m³), W_c : Water demand for cement, W_A : Water demand for aggregate (fine and coarse).

The required quantity of water depends on the workability, type and size of coarse aggregate, grading of fine and coarse aggregate, separated and mixed, and is to be calculated using special tables linking between the grading of aggregate with the quantity of water needed, known as Sterna as shown in Table 2.

6. Calculating the volume of the component materials of the mix using the absolute volume equation, which is the Third Equation of Design (Eq.4), as follows:

$$\frac{W}{1000} + \frac{A}{1000\rho_a} + \frac{C}{1000\rho_c} = 1 \quad (L) \quad (4)$$

Where: C: cement weight (kg/m³), W: water weight (kg/m³), A: aggregate weight (kg/m³), ρ_c : specific gravity of cement, ρ_a : specific gravity of aggregate

7. Solving the three equations of design (2, 3, and 4) for W, C, and A in order to obtain the required quantities

of the components for the mix design according to the specified conditions.

TABLE 1 COEFFICIENT OF A_1 AND A_2 VALUES

Aggregate Shape	Variable	Compressive Strength of Cement (N/mm ²)		
	A	32.5	42.5	52.5
Round	A_1	18	20	21
	A_2	12	13	14.5
Angular	A_1	20	22	24
	A_2	13.5	14.5	16

TABLE 2 WATER INDEX FOR AGGREGATE AND CEMENT

Sieve Size (mm)	Workability (kg / kg materials)		
	Very Low	Medium	Very High
37/19	0.011	0.013	0.016
19/14	0.014	0.016	0.022
14/10	0.017	0.02	0.027
10/5	0.022	0.026	0.034
5/2.36	0.028	0.032	0.044
2.36/1.18	0.037	0.043	0.058
1.18/0.6	0.05	0.058	0.077
0.6/0.3	0.072	0.084	0.112
0.3/0.15	0.104	0.122	0.131
0.15/0	0.205	0.239	0.296
W(cement)	0.271	0.273	0.275

The Experimental Program

This part represented the design and production of a number of concrete mixes following the Three Equations Method and using the local raw materials. This paper illustrated the results obtained by production of five concrete mixes with design compressive strengths of 15, 20, 25, 27 and 30 MPa, where the water-cement ratio (W/C) is 0.76, 0.63, 0.53, 0.51 and 0.47, respectively, and the workability is tested for low, medium and high degrees. These mixes were prepared and produced in the concrete laboratory at the Faculty of Engineering-Tripoli University - by researches carried on by students as a part of the academic requirements for their M.Sc. in Civil Engineering. These concrete mixes were produced following four main stages summarized as follows:

Materials Used in The Mixes

- **Cement:** The cement used is the Ordinary Portland Cement supplied by Zliten Factory for Cement, whose properties have been tested according to the BS12.
- **Coarse aggregate:** The coarse aggregate used in the experiment was angular aggregate with maximum size of 19 mm is used, imported from a quarry near Azizea (nearly 45 km south

of Tripoli city). Tests were carried out according to the BS 882-1992 standards.

- **Fine aggregate:** Natural, fine aggregate used in the mixture was natural beach sand from the Zliten quarry (nearly 200 km East of Tripoli city). The fine sand used has a size not exceeding 2 mm.
- **Mixing water:** Fresh, dirt-free water is used, with a percentage of total dissolved salts not exceeding 2,000 particles per million as per Libyan Standards.

Samples

Standard cylinders of 150 mm diameter and 300 mm height and cubes of size 150x150x150 mm are used as samples to test the compressive strength of concrete. A total of 105 cube samples was cast in average of 7 samples per mix (15, 20, 25, 27 and 30 N/mm²) and a total of 72 cylinder samples were used cast in average of 6 samples per mix per each degree of workability (very low, medium, and high).

Samples Curing

After casting, the samples are covered with a plastic film to avoid evaporation and plastic shrinkage, and are to be left 24 hours in the laboratory environment. Samples are to be marked to distinguish between them and submerged in water at room temperature for 28 days then tested for compressive and tensile strength.

Laboratory Tests

- **Slump Test:** This test is used to determine the degree of workability of the concrete mix in order to watch the consistency of the concrete and check the design workability according to

the British Standards BS 1881-Part 102. Table 3 shows sample of results obtained through this research.

- **Compressive Strength Test:** The objective of this test is to determine the maximum compressive strength of the hardened concrete subject to compressive stresses carried out by putting the samples under a compression on the centerline of the concrete samples used. The load is increased gradually up to failure. In order to assure equilibrium distribution of loads on the cylindrical sample surface, the surfaces were treated using sulphate according to the American Standards ASTM C617-87. The compressive strength is calculated as the mean of seven samples per each mix for cubes and six samples for cylinders, and the test is conducted according to the requirements of American Standards ASTM C39.

For the range of the concrete grades, degree of workabilities, and sample types used different correlation were investigated as the following:

The effect of different degrees of workability on the compressive strength of concrete is shown in Figure 1.

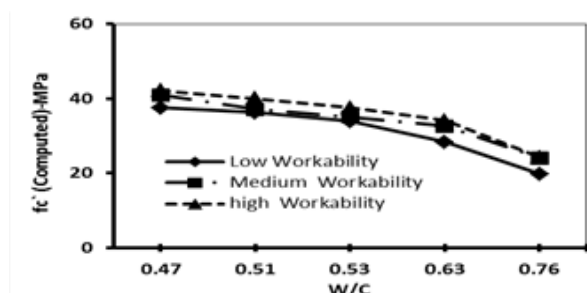


FIG.1 COMPRESSIVE STRENGTH ,W/C and WORKABILITY RELATIONSHIPS

TABLE 3 RESULTS OF FRESH AND HARDENED CONCRETE TESTS

Required Compressive strength (MPa)	Design * Compressive strength Eq.(1) (MPa)	Water-Cement ratio (W/C)	Workability	Slump (mm)	Computed (Lab. Test) Compressive strength (MPa)
15	19.5	0.76	Low	0	19.8
			Medium	30	24.1
			High	94	24.3
20	26.0	0.63	Low	0	28.4
			Medium	70	32.7
			High	100	34.2
25	32.5	0.53	Low	0	33.9
			Medium	96	35.1
			High	120	37.6
30	39.0	0.47	Low	0	37.6
			Medium	120	41.0
			High	170	42.0

* f_c^d (Design) $\geq f_c^c$ (Computed) $\geq f_c^r$ (Required)

A typical relationships between w/c ratio and Compressive strength (f_c') for both cylindrical and cubical samples is demonstrated in Figure 2.

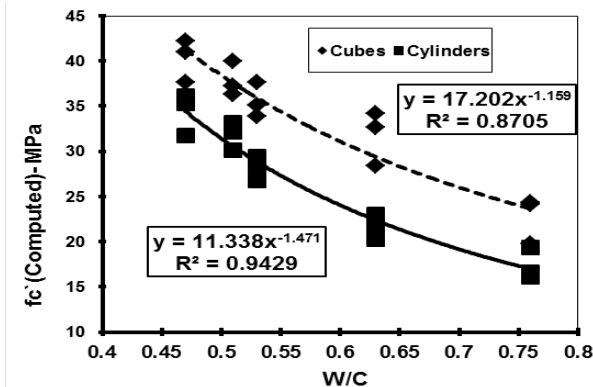


FIG.2 RELATIONSHIPS BETWEEN COMPRESSIVE STRENGTH AND W/C RATIO

As shown in Figure 3, the cube strength is found to be approximately 1.2 times the cylinder strength. In reality, the effect of height to diameter ratio is very difficult to eliminate in a routine test, and not feasible for the range of the strength normally encountered.

Figure 4 shows a typical relation between design and computed compressive strength. Linear relationships with reasonable correlation coefficients were obtained.

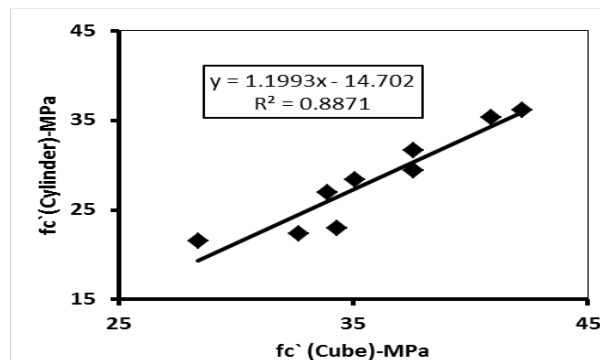


FIG. 3 RELATIONSHIPS BETWEEN CYLINDER/ CUBE COMPRESSIVE STRENGTH

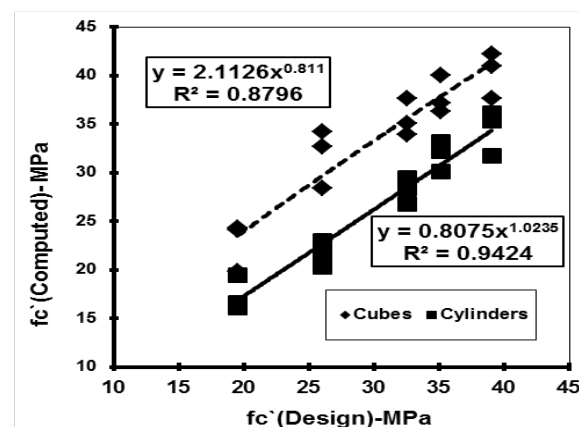


FIG. 4 COMPUTED COMPRESSIVE STRENGTH AND DESIGN COMPRESSIVE STRENGTH RELATIONSHIPS

Discussion

The results obtained from calculations that were carried out for the concrete mix components and quality control tests show that:

1. The concrete mix component ratio obtained using this method is in compliance with that obtained by the common design methods such as ACI and BS methods;
2. The results of the slump test are relatively less than by 5 to 10 in average from the common limits of workability at each degree of workability;
3. This method efficiently meets the compressive strength requirements.

Conclusions and Recommendations

- This method is considered as one of the important introductions to the concrete mix design methods due to the following advantages:
 - o Introduction of the effect of water demand by cement in the design process;
 - o Introduction of the effect of water demand by fine and coarse aggregate as well as the grading in the design.
- In order to make this method more efficient, it is recommended to carry out more researches on tables to give the quantities of water demand by the cement and aggregate for the local raw materials similar to those used in this method (Bolomeya).

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